

Critical current decline of REBCO tapes after heat treatment

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Abstract: This paper describes a research that studied the current characteristics of REBCO tapes in liquid nitrogen after heat treatment at different temperatures. The reason of the deterioration at high temperature is briefly introduced. The conclusion presented in this paper is instructive for the winding of superconducting coils and the fabrication of superconducting magnets.

Keywords: superconducting tapes, heat treatment, superconducting magnet

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1. Introduction

Rare-Earth Barium Copper Oxide(REBCO) tapes has been widely used for building high-temperature-superconducting(HTS) magnets. A special structure called double pancake(DP) showing in pic1(a) is the basic unit of some REBCO HTS user magnets. The current bridge path between two DPs which contains 2 joint on both side of the 2 DPs was made from the same material. Despite of using special low temperature solder, the bridge structure which is actually a short, wide REBCO tape would be exposed to high temperature up to 350°C for a long time while the HTS magnet was built. In order to evaluate the effect of high temperature process on the short samples of REBCO tape, a series of experiments and analysis from the perspective of heat treatment temperature and time were carried out.



图 1 超导磁体中桥接用的短超导带
Fig.1 Bridging tapes in superconducting magnet

2. Experimental

Three kinds of REBCO superconducting tapes from Shanghai Superconductor (SHSC), Superpower and SAMRI were tested. Their basic parameters are shown in Table 1.

表1 超导带材基本参数

Table 1 Fundamental parameters of superconducting tapes

项目	参数		
生产厂家	superpower	SHSC	Samri
平均厚度/mm	0.1	0.1	0.16
平均宽度/mm	4.02	4.1	5.1
最小弯曲半径/mm	25	20	16
最小电流/A	120	130	120

The critical current of each short sample is tested in a liquid nitrogen environment. The test system

includes DC power supply, nanovoltmeter, shunt and multimeter and other equipment. The DC power supply is a superconducting magnet power supply with a current output range of $0 \sim 200A$ for output current. The multimeter and shunt work together to collect the current signal, and the nanovoltmeter collects the voltage signal across the strip. The wire test equipment is shown in Fig.2. The two contacts of the voltage lead on the sample to be measured are between the two contacts of the current lead.

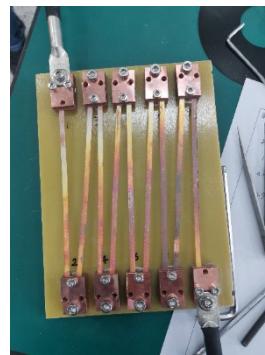


图 2 测试工装与短样

Fig.2 Test equipment and REBCO tapes

The heat treatment temperature range of this experiment is $250^{\circ}\text{C} \sim 350^{\circ}\text{C}$ and the time range is 5 minutes \sim 30 minutes. The temperature and time ranges are based on the temperature at which the superconducting tape may be brought into contact during the fabrication of the superconducting magnet, and the time required for the joint to be welded.

- (1) Superconducting tapes are cut to 130mm each and numbered.
- (2) The strips with the same heat treatment temperature and time are grouped and placed together in a tube heating furnace for heat treatment according to the set time and temperature.
- (3) After the treatment, cool naturally at room temperature and mark the tapes. As shown in Figure 3.
- (4) The treated strips are assembled as shown in Figure 2 and tested for critical current capability under liquid nitrogen conditions.



图 3 (a)管式加热炉 (b)部分处理完毕的超导带材

Fig.3 (a) Tubular heating furnace (b) REBCO tapes after heat treatment

3. Result and discussion

The results of the first stage critical current capability test in 77k after heat treatment are shown in fig. 4 and fig.5. REBCO strips from Shanghai Superconductor (SHSC), Superpower and SAMRI were tested in the experiments.

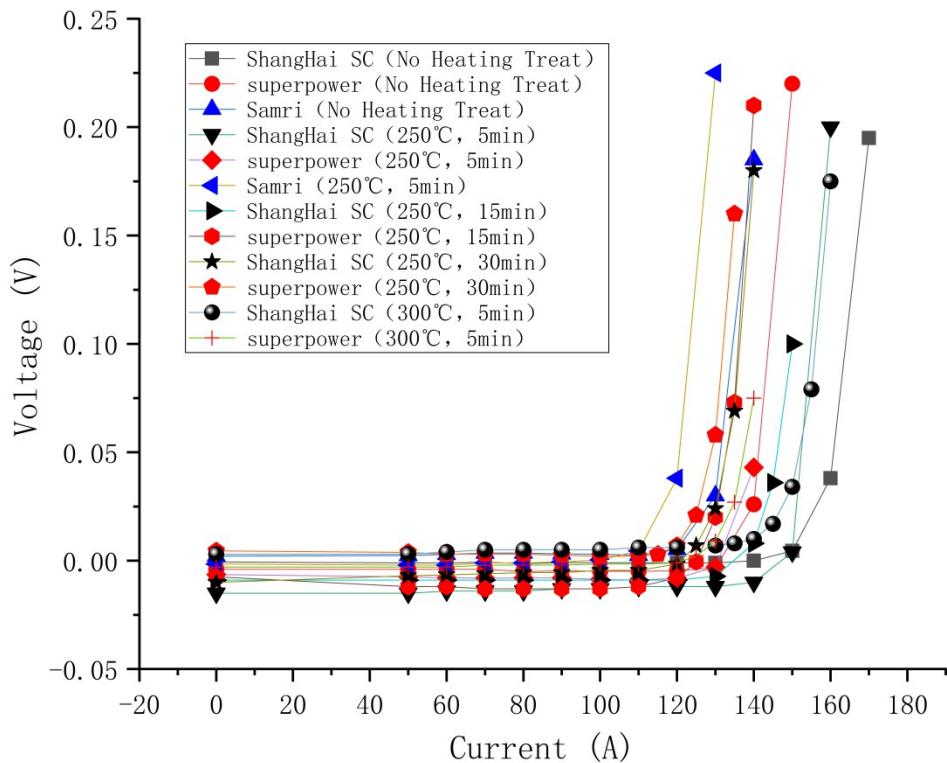


图 4 不同种类的带材在不同温度环境处理后的电流-电压特性曲线

Fig.4 V-I curve of different kinds of tapes after heat treatment

REBCO packaging process of the SAMRI is different from SHSC and superpower using a solder fill method. This manufacturing method results in low physical size consistency of the strip, on the other hand, increases the possibility of phase changes in the REBCO layer during heat treatment. After heat treatment at 250°C/ 5min, the I_c of SAMRI REBCO tapes has decreased by 50%. Higher temperature and longer heat treatment time completely destroys the superconductivity.

Both SHSC and SAMRI tapes showed a better critical current characteristic of 77K than Superpower tapes under untreated and 250°C condition. Under higher temperature and longer heat treatment environments, on the other side, superpower tapes performed better.

SHSC tapes lost 77K superconductivity after heat treatment at 300°C/ 30min and 350°C/ 15min. Superpower tapes still have a limited 77K superconductivity under heat treatment at 300°C/ 30min. The performance of Superpower tapes after heat treatment at 350°C/ 5min is also more advantageous.

The Superpower strip is heat treated in a smaller temperature and time range. Repeated tests of three strips for each heat treatment environment reduce the experimental error and can also quantitatively compare changes in critical current characteristics.

Compared with the 77K critical current (139A) of the untreated short sample, the average 77K critical current after 275 °C/ 5min heat treatment was reduced by 10.6%. The results at 275 °C/ 15min were not significantly different from 275 °C/ 5min.

In the experimentally designed groups of heat treatment environments, the critical currents after 275 °C/ 5min, 300 °C/ 5min, 275 °C/ 10min, and 275 °C/ 15min heat treatment are still maintained at higher levels (> 120A), showing that the risk of high temperature operation is controllable. the critical current at 300 °C/ 10min is lower than the critical current at 300°C/ 25min. Combined with other data, it can be surmised that the REBCO critical current is more sensitive to temperature changes under heat treatment;

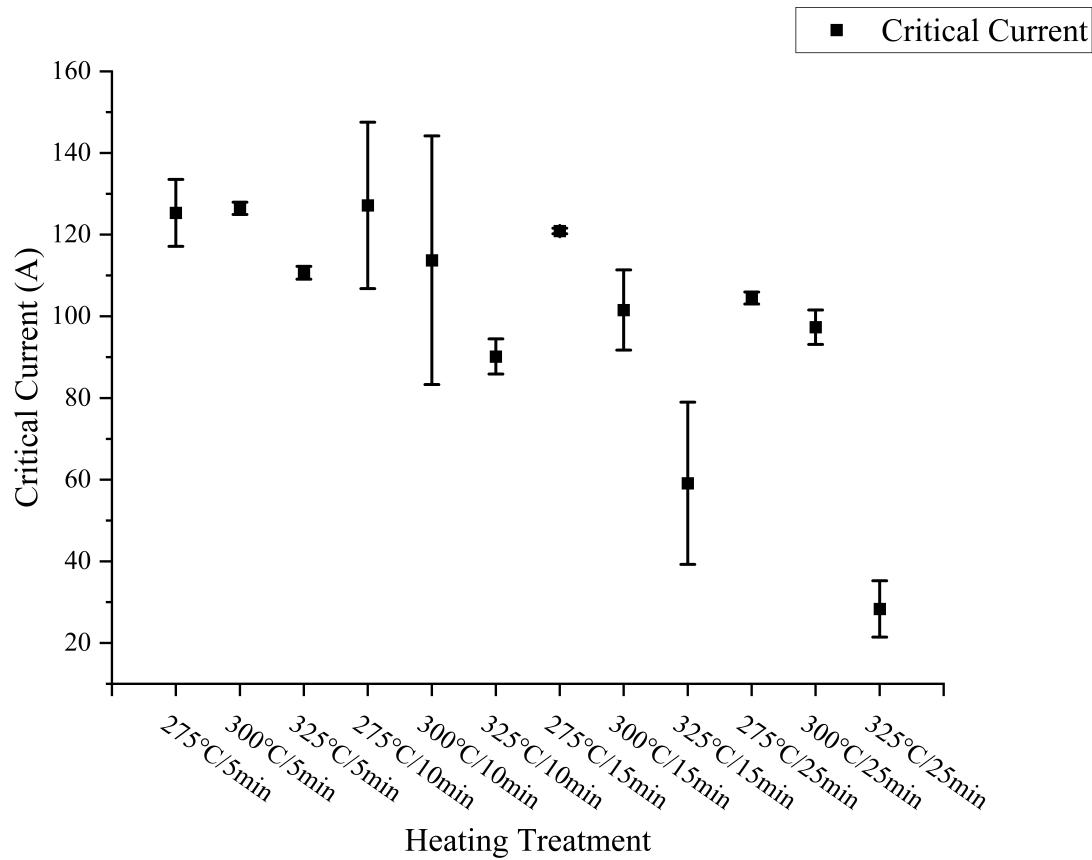


图 5 Superpower 超导带材临界电流随热处理温度和时间变化而变化的趋势

Fig.5 Critical current of Superpower superconducting tape at various heat treatment

The reason for the decrease of the critical current can be understood from the magnetic flux pinning effect of superconducting thin film. To make the 2nd generation superconducting tapes , physical vapor deposition and chemical vapor deposition are used to produce REBCO thin films on flexible metal substrates . In the thin films, A large number of dislocation defects produced by the Volmer-Weber growth mechanism provide considerable amount of pinning centers³⁵. When a current passes through the REBCO superconductor, the Lorentz force generated by these currents will cause the magnetic flux vortex to move and consume energy. That is why REBCO loses its zero-resistance characteristics on the critical current. However, the pinning force generated by the pinning effect can suppress the movement of flux vortex, so that the superconductor can have a high critical current.

During the heat treatment, superconducting thin films at both ends of the short sample are in direct contact with the air, a low-oxygen atmosphere. The high temperature causes the oxygen element in the REBCO film to be precipitated in the form of oxygen gas, which fundamentally changes the

elemental structure of REBCO films in the short sample, thereby causing the dislocation defect to change, and ultimately leading to a reduction in the critical current. The experimental result that Samri's superconducting tapes can not withstand the heat treatment process over 250°C/ 5min due to the particular packaging process also confirms this theory.

4. Conclusions

experiments and analysis after different kinds of heat treatment for REBCO short tapes indicate:

- (1) The processing mode (250°C/5min) that generally regarded as does not affect the superconducting performance, will significantly reduce the critical current at 77K in the experiment;
- (2) The critical current of the REBCO strips decreases as the heat treatment time increases and the heat treatment temperature increases;
- (3) The open package method REBCO tape is not suitable for bridging between double cakes.
- (4) the decrease of the REBCO short tape critical current under heat treatment conditions is more sensitive to temperature changes than the change of time;

In the high temperature process, if the temperature is above 300°C often above 15min, the superconductivity of the strip may be completely destroyed, which should be avoided as much as possible in the production of superconducting magnets. Main reason that decrease the bridge critical current of REBCO magnets is the high temperature and low oxygen environment which destroys the magnetic pinning effect of the superconducting layer. The specific mechanism remains to be further studied.

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